Progress in the Conversion Activity of the Syrian MNSR

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Abstract:

A Coordinate Research Proposal has been signed between the Atomic Energy Commission of Syria from one side and the IAEA from the other side in 2006 to achieve the conversion feasibility studies of the Syrian MNSR. Phase I has been already completed. The outcome of this phase was that the Syrian MNSR could be converted to use the LEU fuel, especially the UO_2 pelletized fuel and cladded in Zircalloy-4. Two types of fuel rods were proposed: the first one is 5.1 mm rod OD and 4.1 mm meat OD, and the second one is 5.5 mm rod OD and 4.3 mm meat OD.

It seems that these fuels can be utilized in the Syrian MNSR with 12.5% and 12.8% enrichments, respectively. The initial excess reactivities would be then 6.1964 mk, and 4.4412 mk, respectively, compared to the initial excess reactivity for the HEU which is ~3.8551 mk. The CRP is proceeding with the Phase II in which fuel selection and thermal-hydraulics calculations for the new fuel will be performed.

KEYWORDS
Reactor, MNSR, Conversion, Reduced Enrichment, Fuel.

1. Introduction

The structure of MNSRs was described several times in earlier works [1-3]. Actually all these reactors (5 outside China) are using the highly enriched UAl_4-Al dispersed fuel cladded in aluminum. This type of fuel has the advantage of a good thermal conductivity (~ 237 W/mK˚), being the Aluminum used as the dispersion material, and low cost of the clad. The technology of aluminum is well known worldwide as well.

The aluminum, from the other side, has the possibility to develop pitting corrosion on its surface for any increase of the water temperature, especially when some impurities are present therein.

The cost of zirconium is relatively high(~ 150 US$/Kg) compared with aluminum cost, and the conductivity is extremely low (22.7 W/mK˚), but the resistance of zirconium and its alloys to corrosion is very high compared with aluminum and its alloys.

The UO_2 ceramic fuel has a very high melting temperature (2650 ˚C) compared with the dispersed fuel (UAl_4-Al) which would be ~ 660 ˚C), which would be a good advantage in terms of thermal safety margin for fuel melting.

For various reasons, among which the availability of the manufacturer, it would be appropriate to select the UO2 as the new LEU fuel for MNSRs.

The suitability of the two above-mentioned UO_2 fuels is analyzed hereafter. The physical properties of the fuels that the calculations use are shown in Table (1).

Table (1) Fuel types and relative physical properties

Fuel Type / Fuel Properties	UAl_4-Al (Dispersed Fuel)	UO_2 Pellets
Meat Density (g/cm^3)	3.456	10.6
Disp. Phase Density (g/cm^3)	5.70	10.6
Wt-% U in Disp. Phase	64.0	88.0
U Dens. in Disp. Phase (g/cm^3)	3.70	9.30
U density in Meat(g/cm^3)	0.955	9.342
Vol. Fraction of Disp. Phase %	26.20	39.0
Porosity %	1.20	0.0
Enrichment %	89.87	19.75
Al content % in the meat	72.310	-
U235 fraction in meat %	24.831	17.405
U238 fraction in meat %	2.80	70.72
Si fraction in meat %	-	-
Mo fraction in meat %	-	-
Oxygen fraction in meat %	-	11.8669

2. Results for the UO2 pellets cladded in Zircalloy-4, 5.1 mm OD

This fuel is considered to be formed of a central meat composed of UO_2 ceramic fuel enriched to 12.5% with the physical properties that can be seen in Table (1).
The meat is introduced in the cladding tube made of Zircalloy-4 alloy. No gap is supposed to exist between the meat and the cladding tube. This is because there is still no information available from the manufacturer about the gap and the filling gas.
The Fuel, Cladd, and coolant temperatures are all assumed to be 20 ºC, since calculations are done for the fresh core.
Table(2) shows some of the reactor neutronic parameters as a function of the fuel used in the reactor.

Table (2) Fuel types and some reactor nuclear characteristics.

Fuel Type / Reactor Neutronic Characteristics	UAl_4-Al (DF)	UO2 Pellets
K_{eff} (Control Rod Out, CRO)	1.00387	1.006235
Initial Excess Rea. (IER) with CRO (mk)	3.8551	6.1964
Deviation from IER (mk)	-	+2.3413
Neutron Flux(Int.Irr. Sites,IIS) ($10^{12}n/cm^2.s$)	0.194738 0.326441 0.474844 1.043610	0.183430 0.311257 0.449116 0.946245
Deviation from Ref . Flux %	- - - -	-5.8067762 -4.6513765 -5.4182005 -9.32963
Neutron Flux(E.I.S) $10^{12}n/cm^2.s$)	0.0213423 0.0419398 0.0850677 0.466349	0.0200831 0.0397093 0.0804466 0.431279
Deviation from Ref . Flux %	- - - -	-5.9000201 -5.3183372 -1.10184121 -8.36198551
K_{eff}(Control Rod In,CRI)	0.996655	0.000040
Reactivity, CRI (mk)	-3.3562	-0.060
Control Rod Worth (mk)	7.2113	-6.2564
Shut Down Margin (mk)	-3.3562	-2.4013
Effective Shut Down Margin (mk)	-0.3773	+0.3519

The reactor parameters listed in Table(2) concern some fundamental quantities for the fresh fuel. The same parameters are brought also for the HEU fuel for comparison.
The Initial Excess Reactivity would be a bit higher if the actual configuration of the reactor were to be kept, so some fuel rods would be removed or substituted with dummy elements.
The neutron flux in the Inner and Outer Irradiation Sites would be lower than that for the HEU by 1-10%. The reactor power should be increased correspondingly by ~10%.
The Control Rod worth is by ~ 1mk lower than that in the case of HEU so that the Shut Down Margin is lower as well. The HEU is safer from this viewpoint.
The Overall Shut Down Margin (indicated as Effective Shut Down Margin) is also lower in the case of LEU than in the case of HEU, because of still the lower CR worth in the case of LEU.
In table(3) some other reactor parameters are brought to the attention of the reader.
The ratio of Hydrogen to U^{235} in the core is well different, and the worth of adding the Top Beryllium Shims is also different. The HEU is more advantageous than the LEU fuel. The effect of filling the Internal Irradiation Sites (IIS), and the External Irradiation Sites (EIS) with water is different in the two cases and should be carefully evaluated especially in the case of an accident.

Table (3) Fuel types and some reactor nuclear characteristics (UO_2 Pellets, 12.5%).

Fuel Type	**U-Al4-Al**	**UO_2**
Reactor Neutronic Characteristics		**Pellets, 12.5%**
Adding Top Beryllium Shims(109.5 mm)-mk	19.0853	16.8605
Enrichment %	89.87	12.5
Ratio of H to U^{235} in core	201.1949	160.342
Ratio of H to U in core	181.0448	20.26654
U^{235} Load in the core (g)	994.6115	1291.261
U Load of 1 fuel rod (g)	3.189402	29.76909
Dummy Elements No.	3	3
Dum. El. Material	Al	Al
Fuel Rods No./ Meat Outer Diameter (mm)	347/ 5.5	347/5.1
Clad Material /thickness (mm)	Al/ 0.6	Zr/ 0.6
Filling Internal Irradiation Sites with Water (mk)	1.9392	+1.7863
Filling External Irradiation Sites with Water (mk)	1.0379	0.9669
Reactivity Regulating Devices Worth (mk)	1.0713	0.8058

3. Results for the UO2 pellets cladded in Zircalloy-4, 5.5 mm OD (12.5% enrichment)

The case of fuel with 5.5 clad OD and 4.3 meat OD is practically the case of the actual loaded fuel (regarded as dimensions). If this fuel is loaded in the reactor the resulting initial excess reactivity would be only 1.3612. The reactor would be critical but it would not have an acceptable IER sufficient to operate the reactor for the prescribed daily operation time.

4. Results for the UO2 pellets cladded in Zircalloy-4, 5.5 mm OD (12.8% enrichment)

If the dimension of the actual fuel were to be kept, and a LEU fuel were to be used in the meat with Zircalloy cladding the enrichment would be increased to 12.8% nearly. In this case the neutronic parameters of the reactor would be that of Tabbs (4) and(5).

The reactor parameters in this case do not differ too much from the case of 12.5% enriched fuel, but the reactor has a good IER.
The safety aspects should be further studied to make sure that these fuels could be accepted for the whole conversion process.

The above-reported results constitute PHASE-I of the CRP which is considered to be already terminated.

Table (5) Fuel types and some reactor nuclear characteristics (UO_2-12.8%).

Fuel Type / Reactor Neutronic Characteristics	UAl_4-Al (DF)	UO2 Pellets(12.8%)
K_{eff} (Control Rod Out, CRO)	1.00387	1.004461
Initial Excess Rea. (IER) with CRO (mk)	3.8551	4.4412
Deviation from IER (mk)	-	+0.5861
Neutron Flux(Int.Irr. Sites,IIS) (10^{12}n/cm^2.s)	0.194738 0.326441 0.474844 1.043610	0.186132 0.3175 0.457428 0.943494
Deviation from Ref . Flux %	- - - -	-4.419271 -2.7389329 -3.6677308 -9.550525
Neutron Flux(E.I.S) 10^{12}n/cm^2.s)	0.0213423 0.0419398 0.0850677 0.466349	0.0203810 0.0403959 0.0818566 0.434427
Deviation from Ref . Flux %	- - - -	-4.5042005 -3.6812288 -3.7747582 -6.8450881
K_{eff}(Control Rod In,CRI)	0.996655	0.998424
Reactivity, CRI (mk)	-3.3562	-1.5785
Control Rod Worth (mk)	7.2113	-6.0197
Shut Down Margin (mk)	-3.3562	-1.5785
Effective Shut Down Margin (mk)	-0.3773	

Table (6) Fuel types and some reactor nuclear characteristics (UO_2 Pellets, 12.8%).

Fuel Type / Reactor Neutronic Characteristics	U-Al4-Al	UO_2 Pellets, 12.5%
Adding Top Beryllium Shims(109.5 mm)-mk	19.0853	17.3379
Enrichment %	89.87	12.8
Ratio of H to U^{235} in core	201.1949	144.3885
Ratio of H to U in core	181.0448	18.68692
U^{235} Load in the core (g)	994.6115	1385.918
U Load of 1 fuel rod (g)	3.189402	31.20319
Dummy Elements No.	3	3
Dum. El. Material	Al	Al
Fuel Rods No./ Meat Outer Diameter (mm)	347/ 5.5	347/5.5
Clad Material /thickness (mm)	Al/ 0.6	Zr/ 0.6
Filling Internal Irradiation Sites with Water (mk)	1.9392	+2.0069
Filling External Irradiation Sites with Water (mk)	1.0379	1.0327
Reactivity Regulating Devices Worth (mk)	1.0713	0.966

5- Future Work in the Conversion Activity

Phase II is now proceeding with the thermal- hydraulic calculations. The possibility of further developing the code HYDMN [4] to include the prompt reactivity insertion problem is being considered whether under or out of the CRP.
That is to enable studying the DBA [5]of the reactor in the case of the new fuel.
The validation of the code would be necessary once the neutronic transient has been added to the code.

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